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Update LADOTD Policy on Pile Driving Vibration Management

INTRODUCTION

Piles have often been used to transfer heavy loads to stronger soil strata or temporarily retain earth or water in highway and bridge construction. The Louisiana Department of Transportation and Development (LADOTD) spends millions of dollars annually on pile foundations. Despite the advantages of driven piles, their installation can cause the surrounding ground to vibrate. The intensity of the vibration depends on the physical properties of the pile (material, weight, length, size, etc.); pile installation method; and the soil (type, density, water content, etc.). Depending on the intensity of ground vibration, it can occasionally cause varying degrees of damage to adjacent buildings and structures or becomes annoying to occupants of the buildings. According to a survey conducted by Woods, 28 State Departments of Transportation (DOTs) and 26 pile driving contractors had experience with vibration claims from driving various piles. In addition, poor public relations or even litigations can result from pile driving operations. Thus, it is imperative for all parties involved in pile driving to have a rational risk management plan that addresses concerns and problems associate with pile driving vibrations.

The extent of structure damage due to pile driving is believed to be related to magnitude of ground vibration that is often quantified in terms of peak particle velocity (PPV). There exists many specifications and provisions that define allowable (or permissible) PPV values. Nevertheless, there is no consensus on a well-accepted allowable PPV value to prevent vibration-induced damage because the complex interactions between piles, soil conditions, and surrounding buildings. One way to address this problem is to monitor vibrations of the surrounding ground during pile driving. For instance, LADOTD has special provisions requiring preconstruction surveys and that contractor to monitor the ground vibration within of 300 to 500 ft. from any pile driving activities.

The impetus for this research was from a recent project where the preconstruction survey distance was arbitrarily expanded to 750 ft. It is LADOTD's desire to update their policy and determine technically sound and reasonable monitoring distances while minimizing risk.

The following aspects of a pile driving risk management plan are needed to address this question: a rational approach to determine relationship between ground vibration levels, soil conditions, and potential structural damage; a rational approach to approximate peak particle velocity of the ground in relation to pile driving activities; and mitigation measures to reduce ground vibrations if needed.

To understand ground vibrations caused by pile driving, it is necessary to consider the following four processes as depicted in (see Figure 1):

1. Wave propagation of the pile-energy is generated as the pile hammer (1) impacts the pile head (2) that is then transmitted down the pile (3);
2. Interactions between soil-pile interfaces- vibrations are transmitted into the surrounding soil [along the pile shaft (4) and at the pile tip (5)];
3. Wave propagates in the ground; and
4. Dynamic soil-structure interactions.

It is of great importance for engineers to have a simple means of predicting PPV values to assess pile driving risk with more confidence with consideration of geotechnical conditions, pile conditions, and pile driving equipment information.

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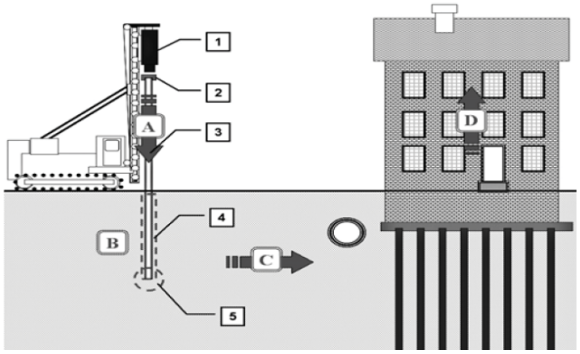

Figure 1 Schematic diagram of an entire process of vibration transmission during pile driving

Woods, R.D., Dynamic effects of pile installations on adjacent structures. 1997, National Academy Press: Washington, D.C.

OBJECTIVE

The objective of this study was to update the current LADOTD policies and specifications on pile driving vibration risk management that include the determination of an appropriate vibration monitoring area, the permissible peak particle velocity of ground vibrations to prevent damage to surrounding structures, and the pre-construction survey area.

SCOPE

This research study carried out an extensive literature review and a questionnaire survey of state DOTs and consulting companies to identify the best practice on the issues pertinent to vibration risk management during pile driving. Based on the current best practice of pile driving risk management, the threshold magnitudes of ground vibrations in terms of PPV were selected for different types of buildings and project soils conditions in Louisiana. Ground vibration data were collected for 10 pile driving projects in the state of Louisiana, which were analyzed on the basis of the scaled-distance concept and from which the ground vibration monitoring distances were determined statistically for different scenarios. The results from the scaled-distance concept, including the threshold PPV and vibration monitoring distance, were further verified with dynamic finite element method (FEM) simulations that are capable of considering other important factors (e.g., ground-structure interactions), which were ignored by the current practice of pile driving risk management.

METHODOLOGY

The current best practice of managing the risk of pile driving by federal and state highway agencies was identified by conducting a comprehensive literature review and a questionnaire survey.

The threshold PPV limits were determined by critically reviewing the current available criteria and specifications suggested by federal agencies and state DOTs.

Ground vibration data were collected from previous pile driving projects in the state of Louisiana, which were statistically analyzed on the basis of the scaled-distance concept to develop regression equations for predicting ground vibration PPV values. A rational procedure for determining an appropriate vibration monitoring distance (VMD) was developed for Louisiana's local conditions based on a 99 percent prediction-level regression equation for predicting PPV values. The findings (the threshold PPV limits and the VMD) obtained from the empirical scaled-distance concept were further verified with dynamic finite element method (FEM) simulations, which considered ground-structure interactions during pile driving and compared the predicted stresses in the structures with their corresponding strength values.

CONCLUSIONS

The results from this research study indicate that the current Louisiana special provision for addressing the risk of pile driving is generally too conservative (e.g., the threshold PPV limit of 0.2 in/s and the pre-construction survey distance of 500 ft.) and should be updated according to the major findings from this study as summarized below. The FEM simulation results indicate that the scaled-distance based findings are quite conservative and simple to be implemented to manage the risk of pile driving.

Threshold Peak Particle Velocity Limits

Two frequency-independent threshold PPV limits were chosen for the following scenarios: (a) the general scenario; and (b) the special scenario with nearby historic/sensitive buildings or settlement sensitive (i.e., loose sand) soil layers existing near pile driving sites. For the general scenario, 0.5 in/s is suggested while 0.1 in/s is recommended for the special scenario.

Vibration Monitoring Distance

The research to analyze the ground vibration data collected from 10 previous pile driving projects in Louisiana, which lead to the recommended VMD for both the general and special scenarios as follows:

- For the general scenario, a VMD of 200 ft. is recommended.
- For the special scenario, a VMD of 500 ft. is recommended for a pile driving hammer with a rated energy equal to or less than 100,000 ft-lbf; otherwise, the VMD shall be calculated as $VMD = 1.6 \times \sqrt{W_r}$, with W_r being the rate energy of a pile driving hammer.

Pre-Construction Survey Distance

The pre-construction survey distance is recommended to be the same as the vibration monitoring distance as summarized in the preceding section, and a pre-construction survey should be carried out prior to any pile driving activities.

RECOMMENDATIONS

Based on the findings from this study, a specification draft is recommended for effectively managing risks associated with pile driving, which is ready for immediate implementation by LADOTD in future pile driving projects and included in Appendix E of the final report. Such a risk management plan for addressing pile driving induced vibrations should be executed not only prior to any pile driving activities, but should be taken into consideration during the planning and design stages as well.